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Response Surface Optimization of Potassium Extraction from Waste Banana Pseudo-Stem

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Abstract

A simple, efficient, and abundantly available agricultural waste material, banana pseudo-stem (BPS) was examined as raw material for the extraction of potassium. The effects of various process parameters such as temperature, initial pH, contact time, banana pseudo-stem dosage and size of banana pseudo-stem particles on potassium extraction efficiency were studied by running batch experiments in Erlenmeyer flasks. Response Surface Methodology (RSM) was used to design the experimental runs. Modelling and optimization of process variables to obtain maximum extraction of potassium from raw material were done using RSM.The maximum extraction efficiency of potassium was found to be 83.96% at a temperature of 400C, pH of 1, contact time of 30 min, BPS weight of 26.076 g and initial BPS size of 300. The results revealed that banana pseudo-stem can be used as good source for potassium extraction.

Keywords: Potassium extraction; Banana pseudo-stem; Response Surface Methodology; Optimization; CCD

Introduction

Potassium is a soft silvery-white alkali metal that oxidizes rapidly in air and is highly reactive with water. Potassium ion is essential for the functioning of all living cells; it assists in muscle contraction and in body metabolism. Potassium levels in a body also affect the functioning of heart [1]. Experimental studies indicated that taking high potassium diet decrease calcium excretion and lowers blood pressure [2]. Potassium metal is very difficult to obtain from its minerals as it is extremely electro positive. However, it is available abundantly in nature as ionic salt. Plant cells, vegetables and fruits are the rich sources of natural potassium and about 22 to 75% of potassium present in these sources is extractable [3].

Researchers investigated the feasibility of using various materials as raw materials such as mango leaves, sorghum Sudan grass, soils, sandstone, phosphate rock, vegetables, water hyacinth, orange peel, bentonite clay, bamboo dust, coconut shell, wheat bran etc. for extraction of potassium [4-11]. Most of these materials are not effective and not economic and produces large amounts of sludge. Therefore, these methods are not suitable industrially because of technical and or economic consideration. Thus, still there is a need to develop cheap and effective source.

Banana is the common name for the herbaceous plants of the genus Musa and is cultivated mainly for its fruit. Banana and plantain trees are grown in every tropical and subtropical region. Banana tree cultivation is the 4th largest food crop of the world [12,13]. In Andhra Pradesh, India, the banana and plantain production was estimated to be 12, 29695 M metric ton and it was found to be 42,550 M metric ton in Visakhapatnam area alone. This figures represents only 10% plant material that is fruit & leaves, remaining 90% of it is (i.e., pseudo stem) wasted. Application of banana pseudo stem for various purposes has been in practice since pre-historic days. Banana fiber is a lignocelluloses material, relatively inexpensive and abundantly available. It is used as insulating material in construction and reinforcing due to its good compatibility and bonding with resin matrix [14,15]. The fiber prepared from banana pseudo stem has long been used in high quality textiles, shelter, tools and flower garlands [16]. Banana pseudo-stem fibers are used in the preparation of sodium carboxy methyl cellulose and cellulose micro fibrils [12,16-19]. Banana pseudo stem fibers also used as resins in ion exchange. Banana leaves are also used as ecologically friendly disposable food containers such as "plates" [3,20]. Studies show that banana peel and pith have very high capacity to remove heavy metals and dyes from wastewater [12,21-25]. Banana pseudo stem was also used in the production of alcohol and methane [26,27].

According to the literature survey done, much attention was not paid on banana pseudo stem as a source of potassium although it contains 5.6–6.2% of potassium [4,28]. The remarkably high potassium content in banana pseudo stem would indicate its potential ability of industrial use. Moreover to an agriculturist, turning agricultural waste into income generating products may be a pet dream. Hence, in the present paper a simple material such as banana pseudo stem was selected for the extraction of potassium ions. Various experimental parameters affecting the potassium extraction process such as temperature, initial pH, extraction time, banana pseudo-stem dosage and size of the banana pseudo-stem particles were studied.

Designing of experiment and standardization of variables affecting the system is very critical in optimization process. Generally this optimization is carried out by using traditional one factor at a time method, which is simple, but time and chemicals are consumed in large quantities. Moreover this method neglects the interaction effects among different process variables. Hence, in the present study statistical approach such as Response Surface Methodology (RSM) was adopted to study the correlation among the different process variables affecting the potassium extraction process. Model is developed to understand

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the potassium extraction process and how it depends on process parameters. Optimization of process variables were also done to achieve higher potassium extraction [24,29-33].

Materials and Methods

Materials and methods

The chemicals such as HCl, NaOH, H_2SO_4 and H_2O_2 used in this study were purchased from Lotus enterprises, Visakhapatnam, India. All the solutions used in this study were prepared by using de-ionized water. Banana pseudo-stem was obtained from a local fruit market in Visakhapatnam, Andhra Pradesh, India. It was washed thoroughly with de-ionized water till no dirt is observed in the effluent water. Then, the whole stem was cut into small pieces of 1-2 cm length and dried in open air for three weeks. After three weeks, this material was grounded in the domestic grinder, and then different sized particles were screened using standard screens and stored air tight containers for further usage.

Experimental procedure

All the process parameters were maintained as per the Central Composite Design for conducting the experiments. Accurately measured 0.8 molar HCl solutions of 200 ml were taken in a Erlenmeyer flasks known amount of Banana Pseudo stem (BPS) powder was added to these solutions and then they were subjected to sonication at known temperature for the predefined time intervals. After completion of predefined time periods, the samples were contacted with 4 molar NaOH solutions for 10 min. Then these samples were centrifuged at 4000 rpm for 15 min. At the end of centrifugation, supernatants and residues were separated carefully. The solid residues are squeezed tightly and liquid effluents are added to previously collected liquid supernatants. Then these samples were contacted with H_2SO_4-H_2O_2 solution for 30 min and were analyzed for potassium ions in flame photometer.

Potassium (K) extraction efficiencies (%KEE) were determined, as described by [10] as a percentage of the extracted potassium relative to the total potassium present in the sample. Apparent potassium extracting efficiencies (%AKEE) were determined as the percentage of potassium remained in the extraction solution after the solid-liquid separation relative to the K present in the sample. KEE effectively represents a maximum theoretical value of AKEE. The following equations were used to determine the %KEE and %AKEE values.

$$\%KEE=(C_0 .V_0/1000). [100/(m_0. X/39.1)] \quad (1)$$

$$\% AKEE=(C_0 .V_1/1000). [100/(m_0. X/39.1)] \quad (2)$$

Where, C_0 is the potassium concentration of the extraction solution after solid-liquid separation (mol L^{-1}), V_0 is the volume of HCl added (ml), m_0 is the weight of sample (g), X is the potassium content of the sample (%), and V_1 is the volume of the extraction solution after solid-liquid separation (ml).

Experimental design and data analysis

The effect of various process parameters such as Extraction time (x_1), Amount of BPS (x_2), Temperature (x_3) and pH (x_4) on potassium removal was studied by using full factorial Central Composite Design (CCD). A CCD with 31 experiments was used for the optimization of process parameters for removal of potassium from Banana Pseudo Stem solution. All independent variables were coded to five levels as X_i and a model was developed for understanding the behavior of the percentage extraction of potassium from Banana Pseudo Stem powder.

Results and Discussion

The statistical analysis of the experimental results shows that percentage of KEE obtained was a function of temperature, pH, time, and amount of BPS. The levels of independent process variables used in a Central Composite Design and the design matrix used with the observed responses obtained were shown in Tables 1 and 2. Responses shown in Table 2 were the average values of three replicates for all the experimental runs. The maximum deviation obtained for potassium values are ±0.035. Apparent potassium extraction efficiency (AKEE) and theoretically maximum obtainable potassium extraction efficiency (KEE) values were calculated and shown in Table 2 for comparison.

The main effects of all parameters on %AKEE were determined at middle levels and shown in Figure 1. The percentage extraction of potassium was increased with time up to 105 min beyond that the change in percentage AKEE was slower. This might be due to the fact that the particles reached equilibrium at 105 minutes; therefore change in extraction efficiency beyond 105 minutes was marginal. These results agree with the results obtained by other researches on potassium extraction [10]. It is noticed from the Figure 1 that percentage AKEE has increased significantly with increased adsorbent dosage up to 35 g however, beyond the dosage of 35 g changes in percentage AKEE was decreased. This might be due to the fact that extraction solution taken is not sufficient to occupy the active sites of entire powder. A plot of temperature versus percentage removal of AKEE shows that the percentage of AKEE increased with increased temperature up to 32.50C and thereafter it showed no change in %AKEE values. This might be due the endothermic nature of the process. At temperature higher than 32.5 stagnant percentage extractions efficiency may be due to the formation of byproducts. Similar temperature effects were obtained with other raw materials also [10]. The effect of pH on percentage of AKEE was studied in the range of pH 1-11. It is apparent from the Figure 1 that %AKEE was decreased with increased pH and reached minimum at a pH of 11. These results indicated that acidic conditions favor the extraction process. Similar results were obtained for effects of all the parameters on %KEE except contact time Figure 2. From Figure 2 it is evident that potassium extraction efficiency increased with increased contact time beyond 105 minutes.

Analysis of Variance was conducted to find the information about quadratic and interaction effects along with the normal linearised effects of the parameters. Second order polynomial equations were developed from ANOVA to represent the effects of above parameters on %AKEE and %KEE and were shown in Equations 3 and 4, respectively.

$$Y_1 = 68.0599 + 1.2112X_1 - 0.8013X_2 + 1.8879X_3 - 3.1871X_4 - 0.6948X_{12}$$

Factor	Symbol	Level				
		-α	-1.0	0.0	1.0	+α
Time, min	x_1	30	67.5	105	142.5	180
Amount, g	x_2	10	22.5	35	47.5	60
Temperature, ˚C	x_3	20	26.25	32.5	38.75	45
pH	x_4	1	3.5	6	8.5	11

Table 1: Levels of different process variables used in CCD for extraction of K.

Time	Size	Amount	Temp	pH	%AKEE	%KEE	%AKEE predicted	%KEE predicted
0	0	0	0	0	68.12	82.56	68.06	82.48
-1	-1	1	-1	-1	62.96	76.41	62.41	76.97
-1	1	-1	-1	-1	72.08	77.24	70.24	75.47
-1	-1	-1	-1	1	62.17	76.87	63.21	75.12
0	0	0	0	0	68.11	82.56	68.06	82.48
0	0	0	-2	0	56.26	70.15	58.64	71.68
1	1	-1	1	-1	62.73	86.59	61.89	85.05
1	-1	-1	1	1	62.76	85.35	63.84	83.67
-1	-1	1	1	1	58.31	72.04	59.16	71.11
1	1	1	-1	-1	68.37	83.99	67.52	83.32
2	0	0	0	0	66.36	84.77	67.7	86.01
0	0	0	2	0	66.96	82.36	66.19	82.24
0	0	2	0	0	60.64	73.12	61.99	73.55
0	0	0	0	0	66.11	80.56	68.06	82.48
0	0	0	0	-2	72.39	87.86	73.56	88.4
-1	1	1	-1	1	49	64.43	47.71	65.69
-1	1	1	1	-1	72.2	86.78	71.58	85.29
-1	1	-1	1	1	65.39	79.76	64.1	80.14
0	0	0	0	2	60.39	74.87	60.82	75.74
0	0	0	0	0	68.12	82.56	68.06	82.48
1	1	1	1	1	68.75	75.06	68.46	76.54
-2	0	0	0	0	62.6	75.95	62.86	76.13
1	-1	-1	-1	-1	66.1	80.11	65.78	79.92
1	-1	1	1	-1	74.68	88.22	74.18	88.85
0	-2	0	0	0	68.95	82.12	68.06	82.48
-1	-1	-1	1	-1	67.28	81.4	68.86	83.39
1	1	-1	-1	1	66.97	80.24	65.46	81.44
0	0	0	0	0	68.12	83.69	68.06	82.48
1	-1	1	-1	1	60.57	77.01	59.53	73.91
0	2	0	0	0	68.84	83.24	68.06	82.48
0	0	-2	0	0	64.95	78.2	65.2	79.18

Table 2: CCD plan matrix in coded values and Responses.

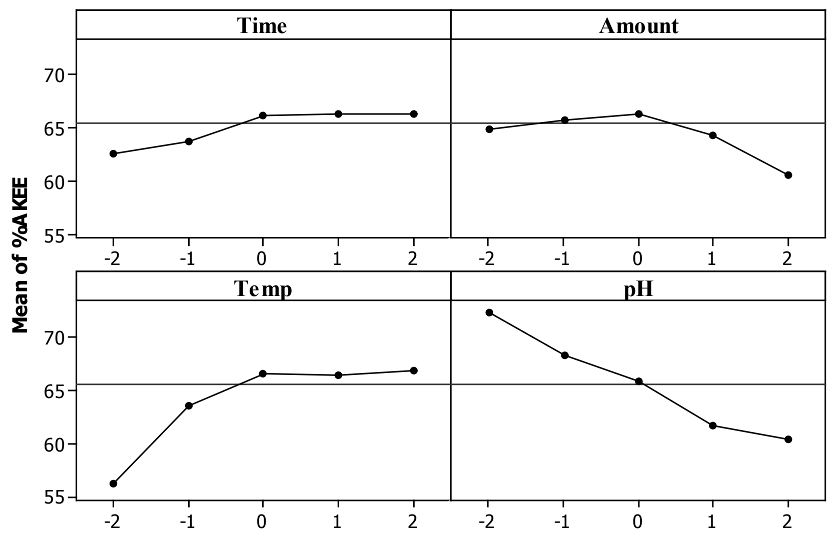

Figure 1: Main effects plot of %AKEE.

$$- 1.1166X_{22} - 1.4119X_{32} - 0.2174X_{42} + 2.3915X_1X_2 - 0.6285X_1X_{31}.6765X_1X_4 + 2.6364X_2X_3 - 1.9176X_2X_4 + 0.5691X_3X_4 \quad (3)$$

$$Y_2 = 2.4773 + 2.4704X_1 - 1.4071X_2 + 2.6386X_3 - 3.165X_4 - 0.3528X_{12} - 1.5278X_{22} - 1.3794X_{32} - 0.1013X_{42} + 0.4749X_1X_2 - 0.6976X_1X_3 + 0.4669X_1X_4 + 0.1008X_2X_3 - 2.7324X_2X_4 - 0.7248X_3X_4 \quad (4)$$

Experimental data along with the predicted results obtained from the above models were shown in Table 2. The proposed models were evaluated by regression coefficients, standard error, t-values, p-values and correlation coefficients (R). The model %AKEE indicates that the temperature, pH and adsorbent dose had a strong effect; linear and

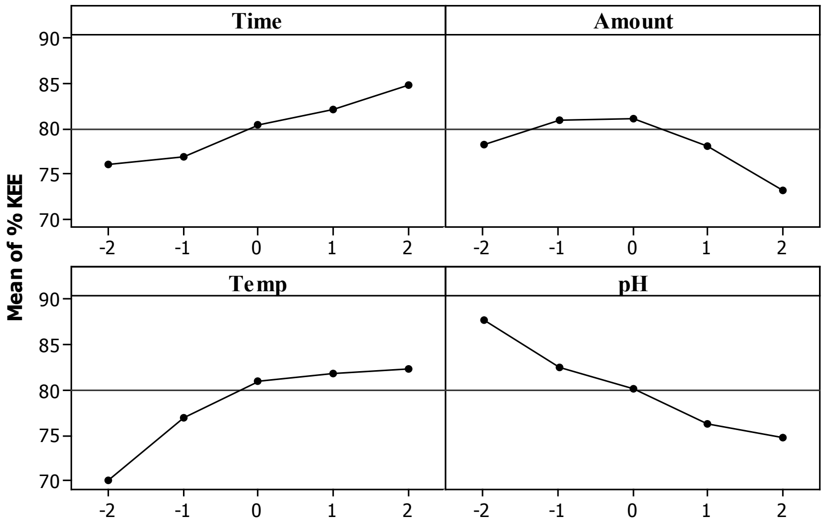

Figure 2: Main effects plot of %KEE.

Term	Coef	SE Coef	T	P
Constant	68.0599	0.5065	134.375	0
Time	1.2112	0.2924	4.142	0.001
Amount	-0.8013	0.2924	-2.74	0.014
Temp	1.8879	0.2924	6.456	0
pH	-3.1871	0.2924	-10.899	0
Time*Time	-0.6948	0.2636	-2.636	0.017
Amount*Amount	-1.1166	0.2636	-4.236	0.001
Temp*Temp	-1.4119	0.2636	-5.357	0
pH*pH	-0.2174	0.2636	-0.825	0.421
Time*Amount	2.3915	0.3581	6.677	0
Time*Temp	-0.6285	0.3581	-1.755	0.097
Time*pH	1.6765	0.3581	4.681	0
Amount*Temp	2.6364	0.3581	7.361	0
Amount*pH	-1.9176	0.3581	-5.354	0
Temp*pH	0.5691	0.3581	1.589	0.13
S = 1.433 R = 0.97877 R^2 = 95.8% R^2 = 92.3%				

Table 3: Response Surface Regression of %AKEE.

Source	DF	SS	Adj MS	F	P
Regression	14	794.944	56.7817	27.67	0
Linear	4	379.944	94.9859	46.28	0
Square	4	96.975	24.2436	11.81	0
Interaction	6	318.026	53.0043	25.83	0
Residual Error	17	34.889	2.0523		
Lack-of-Fit	10	29.674	2.9674	3.98	0.04
Pure Error	7	5.214	0.7449		
Total	31	829.832			

Table 4: Analysis of Variance for %AKEE.

quadratic terms had more influence in comparison to the interaction terms. From the Table 3 it is clear that all parameters effects were significant at 95% confidence levels for % AKEE. Here, the value of correlation coefficient (R=0.978), R^2 (0.958) indicates a high agreement between the experimental and predicted values and its significance. The model adequacy was tested by using ANOVA (Table 4). Lower P values for regression model equation imply that the second-order polynomial model fitted to the experimental results well. ANOVA and regression analysis implies that similar results were obtained for%KEE also (not shown here). High correlation coefficients (R=0.974) for %KEE indicated a higher accuracy between experimental values and predicted values.

The optimum combination of all parameters affecting the percentage AKEE was predicted by using prediction profiler of the software. The maximum extraction efficiency of potassium was predicted to be 83.96% which was obtained at a contact time of 105 min, BPS amount of 35 g, temperature of 32.5˚C, and pH of 1.The above results suggest that Banana pseudo-stem could be used to extract potassium effectively. The residue obtained after the centrifugation process can be further economically used to study for removal of various dyes, metals and other pollutants from the industrial effluents. With the help of above future studies, simple and economically sound commercial method can be designed which would results the environmental gain and commercial benefit to the farmers.

Conclusions

An economical, efficient and eco-friendly natural source was used for the extraction of potassium. Process parameters for the extraction of potassium are optimized using Response Surface Method. A high percentage of potassium extraction, 83.96%, was obtained at the optimum contact time of 105 min, BPS dose of 35 g, temperature of 32.5˚C, and pH of 1.This method may results in reduction of environmental problems without compromising plant productivity and it would also assist in generating income to the farmers.

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